AEROSPACE RECOMMENDED PRACTICE

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ARP 594C

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FUEL PUMP THERMAL SAFETY DESIGN

1. PURPOSE

This Aerospace Recommended Practice (ARP) recommends fuel booster pump design requirements commensurate with the presently known state-of-the-art, relating to the prevention of autogenous ignition of explosive fuel vapors and the confinement of autogenous or spark-initiated flames by means of flame-suppressing devices.

2. SCOPE

These recommendations cover only those design factors which might cause the pump motor or pump housing to act as an autogenous or spark-ignition source for explosive fuel vapors within the airplane tank.

3. GENERAL RECOMMENDATIONS

3.1 Design should be such that under abnormal conditions, such as dragging rotor, locked rotor, internal shorts, etc., the external case temperature does not at any time exceed 400° F (204° C).

3.2 Any device or design expedient used to accomplish 3.1 should be such that it performs its function without producing an open spark in any volume space which contains fuel vapors or any other material susceptible to spark ignition.

3.3 Any device or system design expedient used to accomplish 3.1 should be single action devices, that is, non-resettable.

3.4 Requirements for any device or design expedient to accomplish 3.1 should not materially affect the normal operational reliability of the pump.

3.5 Vents, slots, passages, etc., incorporated in the pump or motor housing, through which flame can travel to external fuel or vapor containing areas should be capable of supressing flame under all normal and abnormal conditions. Explosion-proof testing procedures should consider the pump internal and external surface temperatures, including the flame traps at the local peak values obtained (such as during locked rotor tests), and with fuel cell and external ambient temperatures as specified in the detail specifications for the pump.

3.6 Any device or design expedient used to accomplish 3.1, for fuel cooled motors, are themselves subject to fuel cooling. The accuracy of devices used to accomplish 3.1 is generally dependent ø upon how accurately these devices sense motor temperature. If these devices are being cooled by fuel while they are being heated by the motor, their accuracy can be seriously affected. Consequently, protection of these devices from the cooling effect of fuel should be a design consideration.

3.7 The motor housing design should include provisions to prevent arcing from the motor windings ø to the motor housing in event of winding damage. Electrical arcs from the windings to the motor housing can produce local hot spots and may burn through the housing if high arc energy is available and sufficient differential pressure exists to cause the fused metal to flow.

3.8 It is recommended that a minimum clearance of 0.100 in. (2.54 mm) be provided between motor windings
Ø and the motor housing for 200 VAC, 400 Hz, three phase motors.

4. DESIGN CONSIDERATIONS

The following means of preventing a-c fuel booster pumps from becoming ignition sources in aircraft fuel tanks have been considered in the preparation of this ARP. Appropriate comments are made with respect to the various means considered.

4.1 Motor Design Approach:

4.1.1 Motor Burn-Out: A motor that will burn out in a sufficiently short period of time, if necessary, to limit the maximum pump case temperature to the recommended value.

Note: This method is not recommended, as it does not meet the requirements of 3.2 and imposes a severe quality control problem.

4.1.2 Self-Limiting Motor: A motor which will be left on the power line without burning out or exceeding the recommended value of the pump case temperature.

Note: This approach is not recommended. Further exploration into this type of design approach is advisable.

4.2 Thermal Cut-off Switches: These types of devices can, in general, be recommended with the stipulation that they be contained in a sealed enclosure and that special emphasis to 3.4 be considered.

4.2.1 Motor Protectors:

4.2.1.1 Three phase, wye thermostat with heaters, resetting type.

Note: Not acceptable, as it does not meet requirements of 3.3.

4.2.1.2 Three phase, wye thermostat, with heaters, non-resetting.

Note: Acceptable, but will not protect against internal motor faults.

4.2.1.3 Three phase, six terminal, line thermostat with heaters, resetting type.

Note: Not recommended, as it does not meet requirements of 3.3.

4.2.1.4 Three phase, six terminal, line thermostat with heaters, non-resetting.

Note: Recommend, but presently not available. Adds some internal motor fault protection not provided in 4.2.1.2.

4.2.1.5 Three single-phase thermostats with heaters, non-resetting type.

Note: Acceptable, provided they are connected in line side of motor and that motor will operate on two phases. Ground check for possible 2-phase operation may be necessary.

4.2.2 Thermostats:

4.2.2.1 Three single-phase, line thermostats, non-resetting.

Note: Acceptable, provided they are connected in line side of motor and that motor will operate on two phases. Ground check for possible 2-phase operation may be necessary.

4.2.2.2 Three-phase, wye thermostat, resetting type.

Note: Not recommended, as it does not meet requirements of 3.3.

4.2.2.3 Three-phase, wye, thermostat, non-resetting type.

Note: Acceptable, but does not protect against internal motor faults.

4.2.2.4 Six terminal, line thermostat, resetting type.

Note: Not recommended because it does not meet 3.3.

4.2.2.5 Six terminal, line thermostat, non-resetting type.

Note: Recommended and adds some internal motor fault protection not provided in 4.2.2.3.

4.2.3 Fusible Links:

4.2.3.1 Definition: A metallic component which carries the load current and which opens the circuit by melting at a predetermined temperature.

Ø Note: Acceptable but extreme quality control caution must be exercised in both manufacture and installation in the motor. Fusible links should be installed in such a manner that they unequivocally sense the temperature of the motor phase winding to which they are electrically connected. It is recommended that fusible links be embedded in, or abutted against, the motor windings.

4.2.4 Remote Switching:

4.2.4.1 Thermostat, resetting type with a relay.

Ø Note: Not recommended, as it does not meet requirements of 3.3.

4.2.4.2 Thermostat, non-resetting type with a relay.

Ø Note: Recommended, but may have some effect on the reliability of the system, due to the additional wiring required.

4.2.4.3 Thermocouple or thermistor with a relay which is presently in system for pump that is connected into the pump's electrical power system.

Ø Note: Not recommended as both thermocouples and thermistors are by definition resettable with zero dead band and do not meet 3.3.

4.2.5 Fusible Element Actuated Switches:

4.2.5.1 Definition: A switch actuated upon the melting of a non-load current carrying element.

Note: Not recommended at this time, but design approach looks promising. Final recommendation depends on further testing and field experience.

5. PREPRODUCTION TESTS

Unless otherwise specified in the model specification, pre-production tests shall consist of all tests as
ø listed for the type of device selected. The tests shall be conducted on a population of nine thermal protective devices of the type selected as shown below, and must be conducted essentially in the order listed for each device.

Devices, Nos. 1 and 2

a. Dielectric strength (not applicable to fusible link devices) 5.1

b. Contact resistance 5.2

c. Vibration (Device No. 2 is used for 5.6.3 only) 5.6

d. Inrush current 5.7

e. Contact resistance 5.2

f. Temperature endurance & shock 5.3

g. Actuation endurance (Not applicable to fusible element devices) 5.13

h. Contact resistance 5.2

i. Actuation temperature 5.8

j. Reset temperature (Not applicable to fusible element devices) 5.9

Device No. 3

a. Dielectric strength (Not applicable to fusible link devices) 5.1

b. Contact resistance 5.2

c. Acceleration 5.4

d. Shock 5.5

e. Contact resistance 5.2

f. Actuation temperature 5.8

Device No. 4

a.	Dielectric strength (Not applicable to fusible link devices)	5.1
b.	Contact resistance	5.2
c.	Fungus resistance	5.11
d.	Humidity	5.10
e.	Dielectric test at 75% voltage (Not applicable to fusible link devices)	5.1
f.	Contact resistance	5.2
g.	Actuation temperature	5.8

Devices, Nos. 5, 6, 7, 8, & 9

a.	Explosion proof. Each of the five units shall be used once only.	5.12

5.1 Dielectric Strength: Dielectric strength test voltage of 1500 v (rms) at commercial frequency shall be applied for 1 min. between terminals joined together and case. A dielectric strength test voltage of 1800 v (rms) may be applied for 1 sec. in lieu of the 1-min. test. There shall be no evidence of breakdown.

The above test shall be conducted with a dry unit at room temperature. The application of the voltage shall produce no appreciable transient overvoltages. Subsequent tests shall be conducted as above, except that the voltages shall be reduced to 75% of those specified.

5.2 Contact Resistance (Terminal to Terminal):

5.2.1 Test Equipment:

5.2.1.1 Low voltage output variable transformer power supply with sufficient current rating to supply the normal or rated current of the thermal protector.

5.2.1.2 AC vacuum tube voltmeter of relatively high input impedance with several millivolt ranges suitable for the anticipated voltage drop across the thermal protector.

5.2.1.3 AC ammeter of suitable range for normal or rated current of the thermal protector.

5.2.1.4 A series resistance may be used as needed.

5.2.2 Description of Test Setup: The thermal protector and ammeter are connected in series with the load resistor across the output of the variable transformer power supply. All connecting wires should be of adequate size to carry the normal or rated current for the thermal protector. All connections should be soldered connections. The voltmeter should be connected directly across the thermal protector, terminal to terminal, and adequately soldered. The variable transformer should be connected to the power lines through a switch.

5.2.3 Test Procedure:

5.2.3.1 Temperature-Sensitive-Only Devices, such as 4.2.2 et seq.:

5.2.3.1.1 Test Method: With the variable transformer set for zero output voltage, energize the variable transformer by means of the switch. Adjust the output of the transformer for normal or rated current through the ammeter and read the voltage drop across the thermal protector on the voltmeter. Calculate the contact resistance terminal to terminal. This resistance is expressed by the quotient of the voltmeter reading divided by the ammeter reading.

5.2.3.1.2 Test Conditions: The above test should be conducted at ambient room temperature.

5.2.3.1.3 Change in Resistance: Contact resistance, terminal to terminal, shall not increase by more than 25% when test is repeated in the schedule.

5.2.3.2 Motor Protectors (Temperature- and Current-Sensitive), such as 4.2.1:

5.2.3.2.1 Test method same as in 5.2.3.1.1.

5.2.3.2.2 Test conditions same as in 5.2.3.1.2, except that the device shall be immersed in an oil bath at ambient room temperature.

5.2.3.2.3 The change in resistance, terminal-to-terminal, shall be within the amount stated in the detail specification.

5.3 Temperature Endurance and Temperature Shock:

5.3.1 Purpose: This test is intended to prove the reliability of the thermal protector under prolonged exposure to temperatures near the actuation temperature and under repeated thermal shock conditions, without causing the device to actuate or reset. The application of electric current is not required.

5.3.2 Test Equipment:

5.3.2.1 Suitable air oven and controls to maintain desired temperatures. The heat source shall be so located that radiant heat shall not fall directly on the equipment under test. Ref: Appendix I

5.3.2.2 Suitable container and fluid with means of maintaining the fluid temperature at within 5° to 10°F (3° to 6°C) above the specified low ambient temperature. Ref: Appendix II

5.3.3 Test Procedure:

5.3.3.1 Place the thermal protector in an air oven wherein the temperature is maintained 5° to 10°F (3° to 6°C) below the low limit of the actuation range of the protector. After 16 hr at this temperature, the thermal protector shall be removed from the air oven and, within a period of 1 min., immerse the protector for a period of 15 min. in a liquid maintained at 5° to 10°F (3° to 6°C) above the specified low ambient temperature. This sequence constitutes one cycle.

5.3.3.2 Repeat the above procedure for four additional cycles, except that the exposure to the high temperature shall be not less than 1 hr for these additional cycles.

5.4 Acceleration:

5.4.1 Test Equipment:

5.4.1.1 Centrifuge capable of producing 14 g acceleration.

5.4.1.2 Means of applying rated current to the thermal protector during test.

5.4.2 Test Procedure: With rated current continuously applied, the thermal protector shall be subjected to
ø the acceleration test, per MIL-STD-810C, Method 513.2. There shall be no mechanical failure or protector-actuation due to the applied acceleration.

5.5 Shock: The Thermal Protection Device shall be mounted using its own mounting provisions or means
Ø suitable for its application and subjected to a shock test in accordance with the shock tests per MIL-STD-810C, Method 516.2, Procedure I.

5.6 Vibration:

5.6.1 Test Equipment:

5.6.1.1 Vibration equipment capable of producing and controlling vibration conditions specified herein.

5.6.1.2 Rigid test fixture capable of transmitting the vibration conditions specified herein.

5.6.1.3 Means of controlling ambient temperature between -65° F (-54° C) and the maximum temperature specified herein. Ref: Appendix I

5.6.1.4 Means of applying rated current to the thermal protector.

5.6.1.5 Means of determining whether the thermal protector actuates or resets during test.

5.6.2 Test Procedure:

5.6.2.1 With rated current continuously applied, the thermal protector shall be subjected to vibration test, per
Ø MIL-STD-810C, Method 514.2, Procedure 1A. The resonant and cycling periods shall be divided into three equal parts. The first part shall be conducted at -65° F ± 5° (-54° C ± 3°) the second at room temperature, and the third 5° to 10° F (3° to 6° C) below the low limit of the actuation temperature range.

5.6.2.2 Throughout the test, actuation, momentary interruption of power or any structural failure shall be cause for rejection.

5.6.3 Vibration Scan with Protector Actuated, using device No. 2 for this test only: With the thermal protector actuated, and with indication means supplied, the resonance search shall be run at -55° to -60° F only (-48° to -51° C). Throughout this test the thermal protector shall not reset.

5.7 Inrush Current:

5.7.1 Test Equipment:

5.7.1.1 Recording oscillograph with normal response to 1000 cps.

5.7.1.2 Suitable galvanometers.

5.7.1.3 Suitable power source.

5.7.1.4 Current Transformers or shunts as necessary to match characteristics of the galvanometers.

5.7.1.5 Motor with suitable rating or other device with electrical characteristics that would match motor inrush impedance.

5.7.1.6 A timing switching device that will cycle inrush current in a suitable manner.

5.7.1.7 Protector mounting with realistic simulation of heat sink expected in actual use.

5.7.2 Test Procedure:

5.7.2.1 Description of Test Setup: Leads connecting the thermal protector into the test circuit shall be at least 1 ft (305 mm) long, each, of a gauge appropriate to the protector current rating, and soldered to the protector terminals in the normal manner. Test clips shall not be used. The power source will be connected through the timing device to the thermal protector and to the motor or suitable electrical impedance that will impose a load simulating the motor. Traces for line voltage and amperage will be connected from galvanometers in the oscillograph to the load side of the thermal protector.

5.7.2.2 Description of Test Current Characteristics: The maximum test current shall be 800% of the rated full load current and this shall be reduced in such a manner that there will be no more than 200% of full load current within 0.3 sec. after the first application of inrush voltage, and no more than 100%, nor less than 95%, of full load current within one sec. after the first application of inrush voltage.

5.7.2.3 Test Procedure: The test will be conducted in the following manner:

The switching device will energize the system for approximately 20 sec., once every 2 min., for a total of 1000 cycles. The oscillograph trace will only be necessary on the first and last five cycles to insure proper recording of inrush current and voltage drop. During the 1000 cycles, there shall be no nuisance tripping of the thermal protector.

5.8 Actuation Temperature:

5.8.1 Test Equipment: Temperature checking shall be done in a liquid medium in a container not less than 1 cu ft (0.028 m^3) in volume. The liquid shall be well agitated so that the temperature does not vary more than 0.5° F (0.3° C) from one test point to another in the liquid. The temperature of the liquid shall be determined by an accurately calibrated mercury-in-glass thermometer (calibrated in 0.2° F (0.12° C) increments) which shall be immersed in the liquid to the immersion line on the bulb, near the thermal protector location. A suitable test circuit, such as a continuity meter, or small incandescent lamp(s), shall be connected to the terminals of the thermal protector(s) to indicate contact action.
Ref: Appendix II

5.8.2 Test Procedure: The temperature of liquid shall be brought to a minimum of 2° F (1.1° C) below the lowest allowable operating temperature of the thermostat and maintained at this temperature for 15 min. after the thermostat has been immersed. The temperature shall then be increased at a rate not to exceed 0.5° F (0.3° C) per min. until the thermostat has operated. The thermometer indication at the moment of thermostat operation shall be noted as the thermostat operating temperature.

5.9 Reset Temperature:

5.9.1 For Devices Manufactured to Reset at -65° F (-54° C) or Below ("Non-Reset" Devices):

5.9.1.1 Test Equipment: Reset temperature checking may be done in a circulating air or CO_2 chamber or in a liquid medium. Temperature of the medium shall be determined by an accurately calibrated alcohol-in-glass thermometer (calibrated in 0.2° F (0.12° C) increments) which shall be immersed in the medium to the immersion line on the bulb. A suitable test circuit shall be connected to the thermostat terminals to indicate contact action.

5.9.1.2 Test Procedure: The temperature of the medium shall be held at 1° F (.6° C) warmer than the maximum of the reset temperature specification range or tolerance and the thermostat shall be immersed in the medium for a minimum of 15 minutes. The thermostat shall not reset. If the detail specification specifies a minimum reset temperature the thermostat shall be placed in the medium at the specified minimum temperature and held for 15 minutes. The thermostat shall reset.

5.9.2 For Automatic Reset Devices (Those Which Reset Above -65° F (-54° C)):

5.9.2.1 Test Equipment: Reset temperature checking shall be done with the equipment as specified for actuation temperature checking.

5.9.2.2 Test Procedure: The thermostat, with contacts open and with a suitable test circuit connected to the terminals, shall be immersed in the liquid. The temperature of the liquid shall be held at a minimum of 2°F (1.1°C) above the maximum reset temperature and maintained at this temperature for 15 min. after the thermstat has been immersed. The temperature shall be decreased at a rate not to exceed 0.5°F (0.3°C) per min. until the thermostat has reset. The thermometer indication at the moment of thermostat reset shall be noted as the thermostat reset temperature.

5.10 Humidity: The device shall be subjected to a humidity test in accordance with the humidity tests, MIL-STD-810C, Method 507.1, Procedure I.
Ø

5.11 Fungus Resistance: The device shall be tested for resistance to fungus growth in accordance with the fungus resistance tests, MIL-STD-810C, Method 508.1, Procedure I.
Ø

5.12 Explosion Proof (Non-Hermetically Sealed Units Only): The provisions of MIL-STD-810C, Method 511.1, Procedure II, are applicable, with the following additional detail provisions in the test requirements:
Ø

5.12.1 Test Equipment: The apparatus for conducting the explosion-proof tests shall consist of the following components:

5.12.1.1 A chamber incorporating the following features:

a. A pressure-release system operated automatically by an explosion occurring within the chamber to reduce internal pressure to atmospheric conditions and preclude damage to equipment undergoing test. The system shall be so designed that possible danger to operating personnel shall be minimized.

b. A hinged or removable gasket-sealed door of sufficient size to facilitate installation within the chamber of the equipment to be tested.

c. A means of introducing fuel and maintaining a predetermined fuel vapor-air mixture throughout the test chamber. A fan, or other suitable means, should be used to provide circulation.

d. A window for observing equipment undergoing test, if desired.

e. An ignition source for igniting the explosive mixture within the chamber.

f. Cable ports for the purpose of inserting an assembly of cables, and designed to facilitate a pressure-tight seal around the cables.

g. Openings for installation of pressure-sealed remote controls.

h. A means for reading the temperatures within the chamber.

i. A gauge for reading the pressure within the chamber.

j. A means for maintaining an elevated ambient temperature within the chamber.

5.12.1.2 Auxiliary equipment for use in connection with the chamber shall be:

a. Power sources required for operation of the chamber and power sources and loads for the equipment to be tested.

b. Auxiliary local heating means for actuating the protector, if three times rated current is insufficient for such actuation under the conditions of 5.12.2.3.

5.12.2 High Temperature Test:

5.12.2.1 The mean temperature within the chamber during the test shall be held at 160° to 180°F (71° to 82°C).

5.12.2.2 The chamber shall be sealed at sea-level pressure conditions and the predetermined quantity of fuel shall be introduced to give an air-fuel ratio of 13 to 1 by weight. Fuel used shall be normal butane, 95 minimum MOL per cent purity.

5.12.2.3 Immediately after charging, the thermal protector shall be supplied with normal rated voltage and three times rated current. The thermal protector shall then be actuated. Any explosion within the protector shall not ignite the surrounding explosive mixture.

5.12.2.4 The test shall be repeated for a total of five times. At the end of each test the chamber ignition source shall be fired to determine that an explosive mixture existed during the test periods. Any damage to the unit under test shall be such as to leave the circuit in the open position.

5.13 Actuation Endurance:

5.13.1 Equipment: A suitable test circuit to indicate contact action.

5.13.1.1 High Temperature-For Actuation: A suitable temperature-controlled liquid bath shall be provided as described for actuation temperature checking (5.8.1) controlled at a temperature not less than 25°F (-4°C) nor more than 50°F (10°C) hotter than the nominal actuation temperature of the device.

5.13.1.2 Low Temperature-For Reset: A suitable temperature-controlled liquid bath or atmosphere chamber shall be provided, as described approximately for "non-reset" (resetting at -65°F (-54°C) or below) devices (5.9.1.1) or automatic reset devices (5.9.2.1), controlled at a temperature below the reset temperature but not lower than -150°F (-101°C) for "non-reset" devices, and not lower than -70°F (-57°C) for automatic reset devices.

5.13.2 Test Procedure: The thermal protective device, with test circuit connected to its terminals, shall be subjected alternately to the "high temperature" and "low temperature" environments until ten actuation and ten reset operations take place, accomplishing ten complete cycles of operation.

6. NOTES

6.1 Marginal Indicia: The phi (Ø) symbol is used to indicate technical changes from the previous issue of this ARP.

APPENDIX I

DISCUSSION OF TEMPERATURE CHECKING IN CONTROLLED AIR CHAMBER

The temperature control of an air oven for temperature testing of thermal protectors is difficult, and must be approached with caution and attention to detail, if accurate test results are to be obtained. (See also Appendix II.)

The oven or test chamber must be designed so that a unit under test cannot "see" any heating or cooling surface, else radiation to or from the unit will make its temperature different from the recorded point. The recorded point (thermocouple, thermistor, thermometer bulb, etc.) must be close to the unit under test and subjected to similar conditions of air flow and rate of temperature rise or fall. Uniform circulation is necessary and stratification must be avoided. A "small wind-tunnel" is a good design concept.

It is recommended that control of the test chamber temperature be accomplished by automatic modulating or proportioning means, using a temperature sensing device of small mass, and heating (cooling) equipment with rapid response.

For the environmental vibration test (5.6), the normal vibration apparatus should be supplemented with an enclosure which encloses vibration table mounting plate with test sample installed. The enclosure shall be capable of containing both hot and cold ambients, so that the sample under test may be subjected to environmental test requirements under the extreme environmental temperature condition. Variations of temperature within the test enclosure shall not exceed ± 1°F (.6 C). Environmental test enclosure and related equipment shall be of a design which will not subtract materially from the loading force the vibration table is capable of. In this respect, in Fig. 1 are sketches of equipment which may be utilized as a supplement to standard vibration tables to accomplish required environmental vibration tests at both low- and high-temperature extremes.

APPENDIX II

DISCUSSION OF TEMPERATURE CHECKING IN FLUID

A temperature-controlled oil bath is considered the most suitable means for heating the devices. Moderate agitation and baffling is essential to attain a uniform temperature in the tank. The devices should be located about midway between the top and bottom of the oil test space. Continuity indicators (probably small incandescent lamps) should not draw enough current to affect the operation of the device.

Temperature may be measured either by thermometer or by thermocouple. If the former is used, the rate of temperature change must be low enough to allow for the thermal lag of the instrument. The scale should be located so as to minimize parallax errors. The thermometer should be immersed to the depth prescribed by the manufacturer. The thermometer bulb should be at the same level as the test pieces, and close to them, or within the group.

Calrod units make an easily controlled heat source. The watt density of the surface of the units should be low enough to ensure a reasonable life for the oil. Manufacturers' literature on the subject is readily available. A convenient means for varying the temperatures is by a variable autotransformer (Variac).

The tanks are best fabricated from stainless steel. Rusting can be a problem. Heli-arc welded seams are recommended as less apt to leak.

Safety and ventilating equipment may be required by local ordinance or the policy of the testing agency.

Specimens should be mounted with spacing adequate to prevent their bumping into each other or the sides of the tank. The agitation of the oil need not be violent.

Rate of temperature rise is extremely important.

$$\frac{du}{dt} = \frac{1}{H}(u_o - u)$$

u = Temperature indicated on thermometer

H = Constant depending on medium whose temperature is being measured, its velocity and the construction of the thermometer.

u_o = Temperature of the medium

If a thermometer has been immersed in a fluid whose temperature has been rising at a uniform rate for some time, H is the length of time it takes the thermometer to catch up to where the fluid was at $t = o$. For oil at approximately 7.5 cm/sec. industrial mercury thermometers give an H of about 7 seconds. To restrict the error due to thermometer lag to a 0.25 of 1° F (0.25 of 0.6° C), the rate of temperature rise should be no greater than 2° F (1.1° C) per minute.

$$\frac{du}{dt} = \frac{1}{7}(.250) = .0357 \frac{F}{Sec.} \approx 2.1 \text{ F/min.}$$

This is a maximum rate. When checking devices with appreciable mass, a safer figure would be 1 to 0.5° F every 2 minutes.

For convenience, a brief description of equipment which has been found satisfactory is appended.